Mathematical efficiency calibration in gamma spectrometry for analysis of natural and fallout radionuclides in sediments

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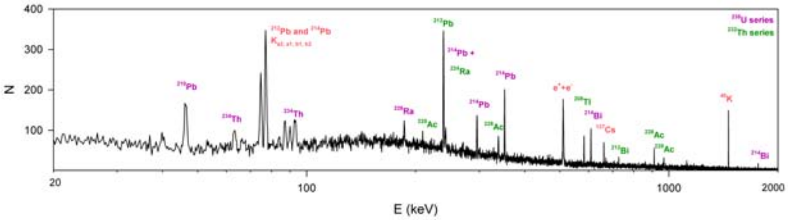
Sediment chronology

Motivation

- Radiometric dating of sediment cores for multiproxy environmental studies
- The least 100–150 years can be covered by gamma spectrometry method
- Isotopes of the main interest: ^{210}Pb, ^{226}Ra, ^{228}Th, ^{228}Ra, ^{7}Be, ^{234}Th, ^{137}Cs, ^{241}Am, . . .
- The main concern in gamma spectrometry of voluminous environmental samples: efficiency calibration



Efficiency calibration

Efficiency determination involves measurement of test sources and calculating efficiencies for given geometry and energy as

$$\epsilon_E = \frac{N_{net}}{t_L \cdot A \cdot I_\gamma},$$

where N_{net} is FEP net count, t_L is counting live time, A is source activity and I_γ probability of emmision of the particular gamma line.

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Efficiency varies with:

- Gamma energy
- Detector to sample geometry
- Matrix density
- Matrix composition

Experimental efficiency calibration in IUP laboratory

- In the IUP laboratory "standard geometries" using calibration sources with gamma-emitters mixture (wide range of energies)
  - liquids: Marinelli beakers, plastic bottles filled into defined heights (1 $g \cdot cm^{-3}$)
  - solids: Marinelli beakers, plastic bottles filled into defined heights, filters and pressed pellets (1, 1.5 or 2 $g \cdot cm^{-3}$)

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Sediment material:

- Different environments and different sources → enormous variability of compositions and densities.
- The matrix of the sample hardly comparable to the standard samples matrix → introducing additional error to efficiency calibration.

Experimental efficiency calibration in IUP laboratory

Density correction of samples with density different from "standard geometries":

- distributing the sample in a larger volume of inactive material (paraffin powder)
- preparing pressed pellets of geometries and densities close to those standard ones

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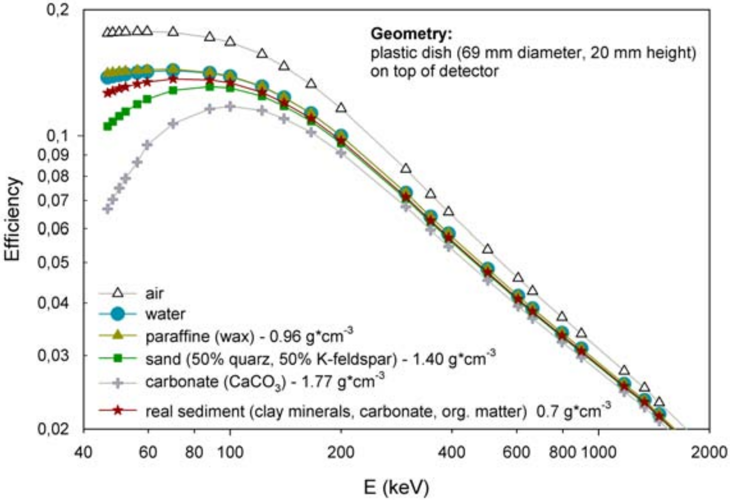
Disadvantages for sediment samples:

- destructive method
- does not take into account changes of self absorption due to elemental composition of the sample matrix

Density and composition effects



Possible solutions for self absorption correction

- Transmission measurements for each sample (Cutshall, 1983; Hurtado et al., 2007) and applying corrections
- Mathematical efficiency calculation: full Monte Carlo calculations with MCNP, GEANT3, GEANT4, ...
- Specialized software, full MC: GESPECOR, DETEFF
- Specialized software, efficiency transfer: ETNA, EFFTRAN, ...
- Manufacturers' mathematical efficiency software: Ortec ANGLE, Canberra ISOCS, LabSOCS

Canberra detector characterization for LabSOCS

- LabSOCS = Laboratory SOurceless Calibration System
- Characterization of detectors:
  - model of the detector: physical dimensions, all internal and surrounding structures
  - modelling by MNCP - FEP efficiency response
  - model is compared to measurements using traceable sources in 5 different geometries - validation, adjustment of unknown parameters and dimensions (e.g., dead layers)
  - large number of efficiency datasets for point sources in vacuum at many locations around the detectors generated (20 energies between 10–7000 keV, 500 m diameter) and a calibration grid for a bare detector is created
  - attenuation due to internal structures of the detectors is calculated and attenuated efficiency grids at 20 energies → detector characterization file
- LabSOCS software calculates efficiency for voluminous samples by integrating the response over the volume of given source

LabSOCS Geometry Editor

Bericht des Geometrie- Editors

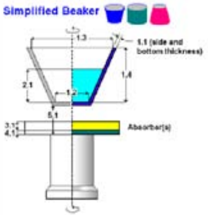
```
Datum:          Monday, June 02, 2008
Beschreibung:   Det3_petri_soil_18mm_69.2_1.2
Kommentar:
Dateiname:      c:\genie2k\ camfiles-working-folder\gamma\anl\pitd
                ana testordner\geo 9501-4\geometry\det3_petri_soil_18mm_69.2_1.2.geo
Software:       LabSOCS
Vorlage:       SIMPLIFIED_BEAKER, Version: cone_or_cylinder
Detektor:       B05007
Umgebung:    Temperatur= 22 C, Druck= 760 mmHg, Rel.Luftfeuchte= 30%
Integration:    Konvergenz= 1.00%, MDRSN= 2^(4) CRSN= 2^(4)
```

Dimensionen (mm):

# Geometriekompon.	d1	d2	d3	d4	d5	d6	Material	D(g/cm3)	R.Konz.
1 Becher	1.30	69.20	69.20	20.00			acrylic	1.17	
2 Probe	18.00						soil_1.0	1.20	
3 Absorber1							none		
4 Absorber2							none		
5 Source-Detector									

Liste der Energien für die Erstellung der Effizienzkurve:

46.5	48.0	50.0	52.0	56.0	59.5	70.0	88.0	100.0	122.1
140.0	165.9	200.0	300.0	350.0	391.7	500.0	604.7	661.7	795.8
898.0	1173.2	1332.5	1460.8	1836.0					

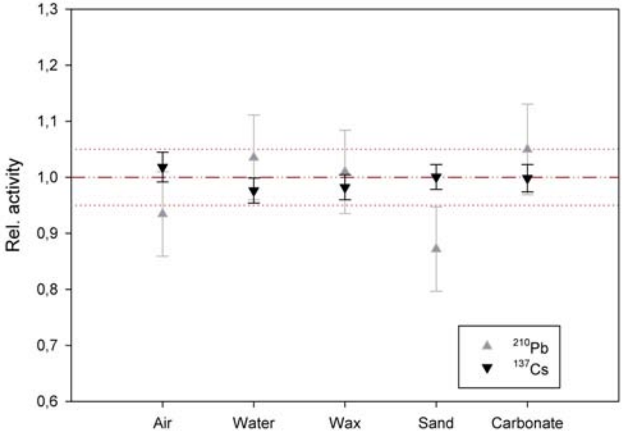


Validation tests

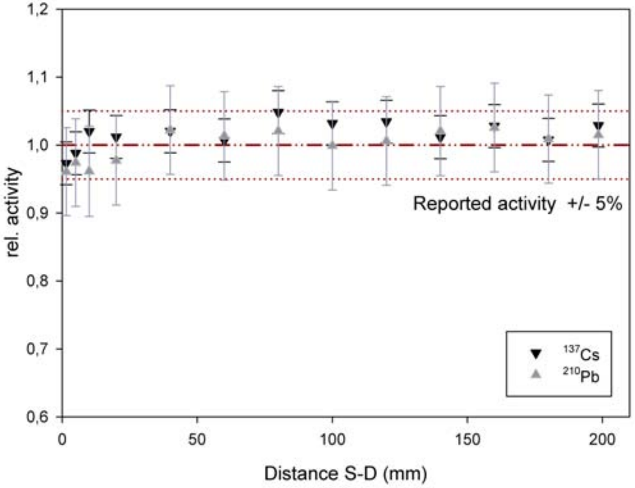
A series of validation tests involving point and voluminous sources in different geometries.

1. a transmission test with point sources and different absorbers
2. point sources measured in different distances from the detector
3. a voluminous source measured in different distances from the detector
4. a soil sample measured in different geometries

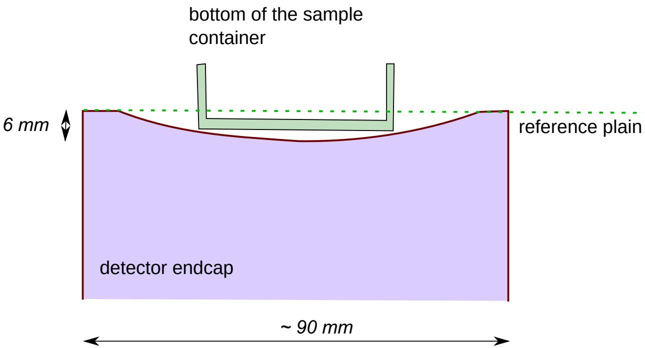
Transmission test with ^{210}Pb and ^{137}Cs point sources and different absorbers



Point sources of ^{210}Pb and ^{137}Cs measured in different distances from the detector

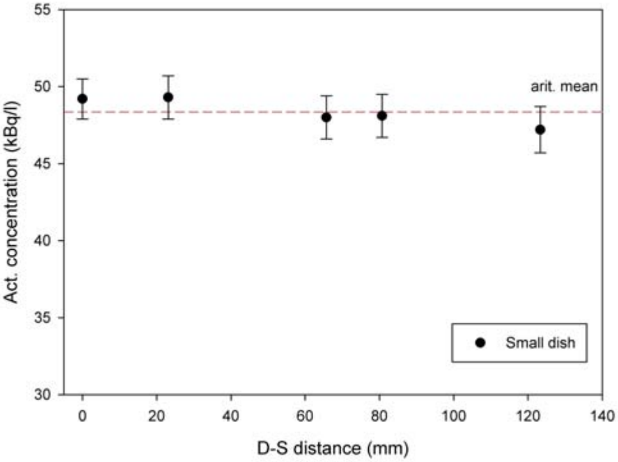


A small comment to "small geometries"

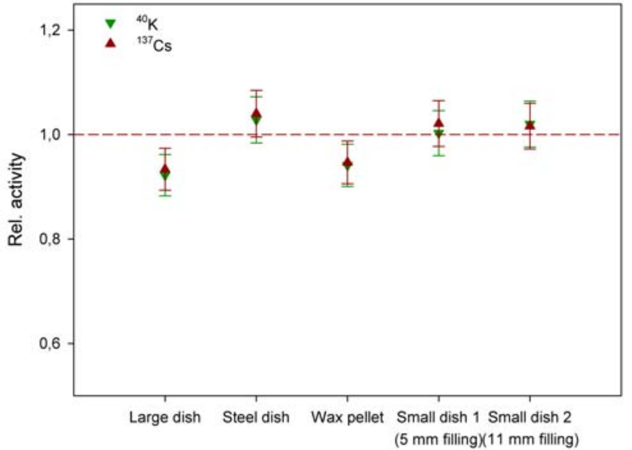


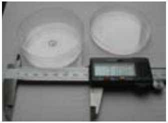
Careful about detector's reference plain (detectors with carbon epoxy window tend to have concave top)

A voluminous source (^{137}Cs solution) measured in different distances from the detector



A soil sample with known ^{137}Cs and ^{40}K activity measured in different geometries

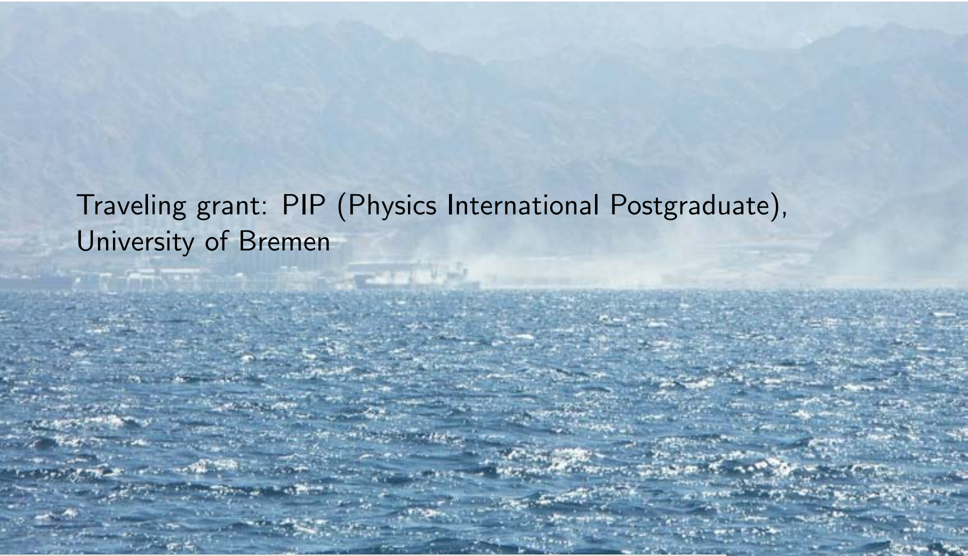




Summary and final remarks

- The claimed accuracy of LabSOCS efficiencies is from 4.3% for energies above 400 keV to 7.1% for 50–100 keV
- Mathematical calibration using LabSOCS: very useful tool, lots of freedom in sample characterization, BUT
- avoid *"blind confidence in factory-calibrated detector"* (Bossus et al., 2006; Gilmore, 2008)
- From Canberra recommended regular quality checks with test kit can only detect changes in detector parameters (growth of dead layer, etc.)
- Based on our experience, also testing LabSOCS efficiency calibration for voluminous samples for each detector is a good idea

Acknowledgments



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